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ENGINEERING AND DESIGN

LABORATORY SOILS TESTING

1. PURPOSE. This manual presents recommended testing procedures for making determinations of the soil properties to be used in the design of civil works projects. It is not intended to be a text book on soils testing or to supplant the judgment of design engineers in specifying procedures to satisfy the requirements of a particular project.

2. APPLICABILITY. The provisions of this manual are applicable to all divisions and districts having Civil Works functions.

3. NOTATIONS, A partial list of the symbols used in this manual appears following the Table of Contents. Not included in the list are symbols used arbitrarily in formulas to facilate computations and those having a special meaning within a particular appendix. All symbols are defined where they first appear in an appendix and wherever restatement may be needed for the sake of clarity. Whenever possible, these symbols correspond to those recommended by the Committee on Glossary of Terms and Definitions in Soil Mechanics of the Soil Mechanics and Foundations Division of the American Society of Civil Engineers.†

4. REFERENCES. The material presented in this manual has been drawn from many sources, persons, and organizations; wherever possible, specific references are given by footnotes. In general, the procedures and practices herein have been taken, under the guidance of the

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† "Glossary of terms and definitions in soil mechanics," Proceedings, ASCE, vol. 84, No, SM4 (October 1958).

Office, Chief of Engineers, from the experience of the U. S. Army Engineer Waterways Experiment Station and the U. S. Army Engineer Divisions. Further contributions have come from Harvard University, the Massachusetts Institute of Technology, the U. S. Bureau of Reclamation, and the American Society for Testing and Materials.

5. TESTING PROCEDURES. Since soils exist in an enormous variety, and since the problems of applied soil mechanics also exist in a very great variety, testing procedures for determining the engineering properties of soils (such as strength-deformation relationships) must not, in fact, cannot, be standardized. Before any soils testing is requested of a laboratory, the design engineer responsible for formulating the testing program must clearly define the purpose of each test to himself and to the person who will supervise the testing.

It is generally necessary to adapt the testing procedures to the specific requirements of an investigation. For example, the consolidation test can be performed in various ways. What is often called the "standard consolidation test" is performed by always doubling the previous load on the specimen. This procedure will produce tin-&-consolidation curves that usually permit the most precise evaluation of the coefficients of permeability and consolidation. However, these load increments are not always satisfactory for defining the preconsolidation pressure from the shape of the void ratio-pressure curve; for this purpose a much smaller factor than 2.0 should be used during incremental loading. Also, the maximum load to which a consolidation test should be continued will depend on the consistency and stress history of the soil and the requirements of the project. For example, if a clay which had been normally consolidated under an effective overburden pressure of 0.5 ton per sq ft is to be loaded by an embankment which will exert an additional pressure of 1.0 ton per sq ft, the consolidation test need not be continued beyond a load of 4.0 tons per sq ft to fulfill the purpose of the test. On the other hand, a highly overconsolidated clay which will be loaded by an embankment of substantial height may require that the consolidation test be continued to a loading of 20 tons per sq ft or more.

An even greater variety in testing procedures exists for measuring the strength of soils, and the purpose of the tests must be constantly reviewed to insure that the results have meaning with respect to design.

Tests which do not measure clearly defined engineering properties (such as Atterberg limits, specific gravity, grain-size analyses, and compaction), however, do require adherence to standardized procedures. Even here the dangers of injudicious testing must be recognized As an example, compaction test results-must be carefully evaluated if the material coarser than 3/4 in. (or some other size) has been removed according to the standard method.

Procedures for soils tests necessary for the design of Civil Works projects appear as appendixes to this manual. The procedures are considered to represent the best current guidance for obtaining acceptable de sign data, Deviations from these procedures may be necessary on occasion, according to the judgment of testing or design engineers, their experience with local soils, or peculiarities of a project. However, to insure that the test methods remain compatible with the purpose of the tests and that the results will be acceptable, every such deviation should be discussed in advance with the design office requesting the tests or, if in the judgment of the design engineer such deviation represents a major departure from the conventional procedure, should be first approved by the Office, Chief of Engineers. Also, a description of any non-conventional procedure must accompany the test data.

6. RELIABILITY OF TESTING APPARATUS AND RESPONSIBILITY OF PERSONNEL, All who are engaged in soils testing must constantly be aware of the importance of accuracy in measurements. Inaccurate measurements will produce test results which are not only valueless but are misleading. Each appendix to this manual contains a list of the more common possible errors associated with the procedures described in that appendix. Serious errors can be caused by poorly constructed apparatus (for

example piston friction in triaxial compression chambers or rough-finished consolidometer rings), by maladjusted apparatus (liquid limit devices, proving rings, or mechanical compactors), and by worn parts (liquid limit cup or grooving tool or knife edges of lever systems). Regular calibration and inspection must be a standard practice in all laboratories.

The personnel performing the tests must be thoroughly familiar with the apparatus, the testing procedures, and good laboratory technique in general. They must be conscientious in the handling of soils and must appreciate the purpose of each test they perform. Neat, thoughtful work, with the recording of all test data and a continuous watchfulness for irregularities can prevent most errors. The philosophy should be that one good test is not only far better than many poor tests, but is also less expensive and less likely to permit a misjudgment in design.

7. LABORATORY FACILITIES. A laboratory preferably should be on a ground floor or basement with a solid floor and should be free of traffic and machinery vibrations. Separate areas should be designated for dust-producing activities such as sieve analyses and sample processing. Temperature control of the entire laboratory is to be preferred. If the temperature-controlled space is limited, this space should be used for triaxial compression, consolidation, and permeability testing. A humid room large enough to permit the storage of samples and the preparation of test specimens should be available.

8. SAMPLE HANDLING AND STORAGE. The identification markings of all samples should be verified immediately upon their receipt at the laboratory, and an inventory of the samples received should be maintained. Samples should be examined and tested as soon as possible after receipt; however, it is often necessary to store samples for several days or even weeks to complete a large testing program. Every care must be taken to protect undisturbed samples against damage or changes in water content Such samples should be stored in a humid room and may require rewaxing and relabeling before storage. Except for special purposes,

such as for viewing by designers or contractors or for research, soil samples should not be retained for long periods; even the most careful sealing and storing of undisturbed samples cannot prevent the physical and chemical changes which, in time, would invalidate any subsequent determinations of their engineering properties.

9. SELECTION AND PREPARATION OF TEST SPECIMENS. Under the most favorable circumstances, a laboratory determination of the engineering properties of a small specimen of undisturbed soil gives but an approximate guide to the behavior of an extensive nonhomogeneous geological formation under the complex system of stresses induced by the construction of an embankment or other structure; under the worst circumstances such a determination may have no meaning. Also, the strength, compressibility, and permeability of a soil in place may vary severalfold within a few inches. No other aspect of laboratory soils testing is as important as the selection of test specimens to best represent those features of a foundation soil which influence the design of a project. The selection cannot be based on boring logs alone, but requires personal inspection of the samples and the closest teamwork of the laboratory personnel and the design engineer. This cooperation must be continued throughout the testing program since, as quantitative data become available, changes in the initial allocation of samples or the securing of additional samples may be necessary.

Second in importance only to the selection of the most representative undisturbed material is the preparation and handling of the test specimens to preserve in every way possible the natural structure and water content of the material. Indifferent handling of undisturbed soils can result in test data that are erroneous by several times any errors caused by faulty testing apparatus. With but few exceptions, test specimens should always be prepared in a humid room. Trimming instruments should be sharp and clean and the specimens should be adequately supported at all times; details of the preparation equipment and procedures are presented in the appendixes to this manual. What cannot be gained from any manual, however, is the judgment and awareness necessary to adjust the techniques for each type of material in order to secure the most satisfactory specimens.

During the preparation of specimens, the laboratory personnel have the best opportunity to record a complete description of the material and to judge whether the material is truly undisturbed. The description should include an identification of the material, its color and consistency, the brittleness of the material and the loss of strength upon remolding, and any heterogeneity or unusual characteristics which might prove valuable in analyzing the test results. Also, any indication of disturbance of boring samples (strata deformed at periphery or distortions concentric with axis of sample) must be noted. Often these distortions cannot be seen except by slowly drying a slice of the material to a water content at which the differences between strata show clearly.+ Photographs of such partially dried slices may be helpful when evaluating the test data and can contribute to improvements in sampling equipment and techniques. Disturbed samples should never be used for any tests other than classification, specific gravity or water content.

10. DATA SHEETS AND REPORT FORMS. Examples of suggested form sheets for recording and computing test data are presented in the appendixes hereto, and some appendixes show the forms to be used for reporting test results. The data sheets shown may be satisfactory in many instances, though each laboratory should adopt whatever data sheets are most suitable for their
* practices and apparatus. ENG Form 2086 should be used for presentation of a summary of soil test data in design documents. Well-planned data sheets *
can improve the efficiency of testing and, by encouraging the recording of data which otherwise might be lost, can lead to better testing.

The report forms shown in the appendixes have been developed to facilitate the review of design memoranda of Civil Works projects.

+ M. J. Hvorslev, Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes, U. S. Army Engineer Waterways Experiment Station, CE (Vicksburg, Miss., November 1949).

Because they are intended for review purposes, these forms often do not display the test results in sufficient detail for interpretation by the design engineer. Therefore, each laboratory should include with the standard report forms whatever tabulated or plotted data are necessary to satisfy the purpose of a testing program. Graphs should show all the plotted points, not just smooth curves, and be given scales in easily read units, such as 1, 2, or 5 divisions per unit. The report form should contain a complete description of the material, not just the classification, and sketches to illustrate the mode of failure of strength test specimens.

FOR THE CHIEF OF ENGINEERS:

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15 Appendixes
- APP I - Water Content - General
- APP II - Unit Weights, Void Ratio, Porosity, and Degree of Saturation
- APP III - Liquid and Plastic Limits
- APP IIIA - One-Point Liquid Limit Test
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